Journal of the Royal Society of Arts

NO. 4899 FRIDAY, 15TH MAY, 1953 VOL. CI

FILM EVENING

All the tickets for the showing of *Louisiana Story* on Wednesday, May 20th, at 7.30 p.m., have now been issued and the Secretary regrets that he cannot accept any further applications. A few seats near the screen will be available, if desired, for any Fellows or their friends without tickets.

Refreshments will be served in the Library afterwards, as usual, at a charge of one shilling per head.

PROPOSED RECEPTION FOR OVERSEAS FELLOWS

In the *Journal* of the 20th February, it was announced that the Council hoped to arrange a social function for overseas Fellows visiting London for the Coronation and those interested were asked to notify the Secretary accordingly.

Unfortunately the response to this notice has been very small and the Council have therefore reluctantly decided not to proceed with the proposal.

MEETING OF COUNCIL

A meeting of Council was held on Monday, 11th May, 1953. Present: Mr. E. Munro Runtz (in the Chair); Mr. F. H. Andrews; Mr. A. C. Bossom; Sir Frank Brown; Mr. Wells Coates; Sir Edward Crowe; Professor E. C. Dodds; Mr. John Gloag; Sir Ernest Goodale; Mr. A. C. Hartley; Dr. R. W. Holland; Lord Horder; Mr. Hugh Lyon; Mr. F. A. Mercer; Mr. O. P. Milne; Mr. E. M. Rich; Mr. Gordon Russell; Sir Harold Saunders; Sir John Simonsen; Professor Dudley Stamp; Mr. L. A. Terry; Mr. William Will; Mr. J. G. Wilson, and Sir John Woodhead; with Mr. K. W. Luckhurst (Secretary) and Mr. R. V. C. Cleveland-Stevens (Assistant Secretary).

ELECTIONS

The following candidates were duly elected Fellows of the Society:

Bettencourt, Jorge Derrick, Manchester.
Birrell, Max Neville, Adelaide, Australia.
Broughton, Geoffrey, B.A., Hull, Yorks.
Davies, Miss Katharine R., London.
Dixon, Malcolm, M.A., Ph.D., Sc.D., F.R.S., Cambridge.

Eliovson, Ezra, Johannesburg, South Africa.
Fairburn, Ernest Granville, Gainford, Co. Durham.
Fraser, Ronald George Juta, B.Sc., Ph.D., Paris, France.
Graybow, Michael, London.
Hilyer, William John, B.Sc., M.I.C.E., M.I.E.E., London.
Jacob, Leslie Herbert, London.
Lamb, David Ernest, Whitstable, Kent.
Lawlor, Adrian, Warrandyte, Victoria, Australia.
Leedham-Green, Hugh Lascelles, M.A., London.
Lund, Lt.-Gen. Sir Otto Marling, K.C.B., D.S.O., London.
Lunt, Robert Winstanley, M.Sc.(Eng.), Ph.D., C.I.Mech.E., A.M.I.E.E., London.
McBride, James Patrick, Glasgow.
Marks, Ronald Hanley, B.Sc., Rondebosch, South Africa.
Maxwell-Cook, John Charles, A.M.I.C.E., M.I.Struct.E., Brighton, Sussex.
Pearce, Joseph Pearce, F.R.I.B.A., West Kirby, Cheshire.
Redman, Major Reginald John, M.B.E., Khartoum, Sudan.
Rodway, Cecil George Reedon, Livingstone, Northern Rhodesia.
Russell-Sienesi, Alan, M.C., Beverley, E. Yorks.
Salmon, John Ernest, B.Sc., Ph.D., London.
Throssell, Eric Ronald, Dorchester-on-Thames, Oxon.
Tonge, George Edward, Dorking, Surrey.
Twizell, Robert Percival Sterling, F.R.I.B.A., Vancouver, Canada.
Vaillancourt, Major Roland, M.A., Montreal, Canada.
Wiggill, John Bentley, B.Sc., Rondebosch, South Africa.
Yoors, Eugene, Purley, Surrey.

The following candidate was duly elected an Associate Member of the Society:

Mallen, Miss Jean Margaret, Burnholme, York (Examinations Silver Medallist).

The following Colleges were admitted under Bye-Law 66:

The Brighton College of Art and Crafts.
The Mid-Warwickshire College of Further Education, Leamington Spa.
The Nuneaton Technical College and School of Art.
The Rugy College of Technology and Arts.

ALBERT MEDAL FOR 1953

Final consideration was given to the award of the Albert Medal for 1953 and a name was selected for submission to His Royal Highness the President.

BALLOTING LIST

The preparation of the balloting list for the new Council was completed.

EXAMINATIONS

It was reported that the total number of entries for the Whitsun series of examinations was 37,956 as compared with 32,657 in 1952.

ANNUAL GENERAL MEETING

It was decided that the Annual General Meeting should be held on Wednesday, July 1st, at 3 p.m.

OTHER BUSINESS

A quantity of financial and other business was transacted.

THE SAFETY FACTOR IN CONSTRUCTION

Two Cantor Lectures

I. STRESSES AND THE THEORY OF STRUCTURES

by

G. ANTHONY GARDNER, O.B.E., M.I.Struct.E.,

Chief Structural Engineer, Ministry of Works

Monday, 23rd February, 1953

The building of structures with a margin of strength over and above that necessary for the net stability of the structure in use has been the practice of engineers since the time when theoretical static mechanics began to evolve as a scientific approach to design; and, indeed, prior to that, the idea of having something "in hand" was undoubtedly present in the minds of the constructors who built empirically. This exemplification of prudence is, of course, in line with the precautions which we adopt in most other constructive activities and is not a mental complex peculiar to structural engineers. We start off therefore with the idea that human caution suggests that in any structure we should have a potential strength somewhat greater than that which is barely necessary when the structure is in normal use.

This sounds delightfully simple and if our practical knowledge of metallurgy, our analytical skill and our qualities of materials and our workmanship were to an absolute standard we could adopt a safety margin of a few per cent, just to satisfy the philosophy of abstract caution. But when we come down to engineering as a practical art it is borne in upon us that the problem is beset with many difficulties.

At a time like the present, when economy in the use of structural materials is imperative, we may say that the problem of the factor of safety takes on a political significance, and the engineer and physicist are required, as a matter of ethics, to push the margin to that minimum beyond which it would, in fact, be risky to go. From the layman's point of view this criterion is perhaps satisfied if it could be demonstrated that a structure evinced signs of incipient failure when it was subjected to loadings a fraction over those which it had apparently safely withstood for some years in normal use; but even in this case an agreement on what constituted incipient failure would not be reached without deliberation and a consensus of opinion. A complete catalogue of the signs and conditions by which incipient failure could be adjudged would occupy us far too long this evening, and the criteria would vary with the type and purpose of the structure. For example, we might, on the one hand, have a laboratory floor on which

delicate measuring instruments were required to be installed and in which any significant deflection would constitute a failure in stiffness, and on the other hand a gantry in which sway and other deformations were of no practical account and in which no trouble would arise until pronounced yield took place.

We may say that there are two primary types of failure to be guarded against; namely, deformation to unserviceability, and progressive overstressing and breakdown of resistance.

The first of these may have to be related to conditions of use and, in some cases, to æsthetic or psychological considerations—as, for example, where even the appearance of deflection is objected to or where the sensation of springiness is unpleasant—and in the second category we may have to take into account the phenomenon of fatigue, that is, the lowering of initial strength due to a great many repetitions of the stress cycle resulting from successive loadings.

Deformation to unserviceability may, in certain cases, have very little relationship to the factor of safety as such, although in these very instances it can lead to trouble in things whose functioning may be interfered with, as when mechanical line shafting in a workshop takes bearing from a structure which may vibrate in a heavy gale of wind. Let us, however, consider this first type of an approach to failure in more detail and see how it is a formative consideration in this factor we are considering. I must make an apology to those of my own profession who may be among us listening to this discourse, but I feel that we should all be wasting our time if I failed to lay bare the subject at issue so that we may review what we are up against in seeking for maximum efficiency.

As I have indicated, the designer must be actuated by the layman's criterion of fitness for purpose, and any deformation of the structure which may lead to inconvenience or to cracking or other damage must be avoided. This may be illustrated by a cable suspension bridge in which a stiffening truss is needed, not primarily to carry the load, but to distribute its effect so that rhythmic vibration, due, for example to soldiers in step or to the periodical passing of vehicles may be damped. The relationship of this to the factor of safety is complex and the skill of the designer consists in bringing about the desired effect with a minimum of cost. Also the ultimate load which the bridge would take in years to come might depend on the degree to which the stress range in the various members of the bridge can be kept down by the stiffening device, and in consequence the life of the bridge, as well as its margin of strength at any point of time, must figure in this factor.

You will, therefore, see from the few cases I have cited, how complex this question is and that it may have a time element in it as well as a mere mechanical relationship. Supposing, however, that in any form of structure we wished to design and construct it with that small margin which would just ensure strength and stiffness throughout the period of use for which we required it, we are nevertheless faced with a number of fundamental difficulties. The expected variations in the mechanical properties of the materials we are using (for simplicity, let us suppose it to be steel) could be known with practical accuracy and we could select lower-limit values for its strengths in direct compression,

tension, shear and bearing, and also for its elasticity in the several states compatible with these stresses. We could also compute with practical accuracy all the loads and forces to be resisted and we could insure that the workmanship in the finished structure was perfect. It would therefore only remain to design the structure in its several parts and make drawings from which the fabricators and erectors could work. But here the trouble starts, for when we come to investigate that very extensive science which the engineer, with the help of physicists, has built up over about two centuries, and which we designate the Theory of Structures, we see that it is a concatenation of rational approximations and not a series of absolute values. And this being so, it means that some element of caution—some engineering discrimination—has to be exercised in using the theories; in other words, that a margin has to be allowed for those elements in any theoretic approximation which are virtually unknowable. In addition to this we have to take account of the fact that the discrimination to which I referred is an attribute of experience and that in order to carry on the business of an engineering office it has been found necessary to devise certain rules and customs which themselves are further approximations. In this connection we must not lose sight of the fact that the efficiency of human energy is a very important factor in nearly all constructive activities and that the business of an engineer is no exception to this, and that in the process of earning his living—in the perfectly normal desire to preserve a factor of safety financially—he cannot, except in very special instances, press his investigations beyond that reasonable limit which formulæ, rules and customs have sanctioned and which experience has shown to be justified.

We therefore see that the basic processes of design must embody some factor of safety to cover the approximations inherent in fundamental theories and the further approximations which arise from rational simplifications of these theories in use in the process of earning a living as an efficient member of society. Unfortunately the precise value of these factors themselves cannot be laid down with absolute certainty in any particular case and they have therefore to be lumped in with the general factor to which it is customary to subject either the basic yield stress of the material or the loads on the structure, or, indeed, both. Not only must these intrinsic approximations be present in our working theories but they have a varying significance according to the type of structure and the nature of the parts of the structure under consideration, and this is a further complication which I will touch on presently, namely the effect of the type of structure itself on the significance of the various theories which may be employed in the process of designing its parts.

In order to clear the ground as far as may be in a general lecture of this nature I think it important that the layman should follow in detail a typical explanation of what this inherent approximation amounts to in these basic theories. Let us take the theory of beams, or members subjected to cross bending. We cannot perceive the complicated functioning of a beam but must apply the simple law of the lever and puzzle out how it is that the external leverage resulting from the weight on the beam and the counter resistance of the supports is resisted by an

internal leverage. Galileo was one of the first to try and puzzle this out in the seventeenth century but not knowing Hooke's law, namely the general relationship between the force and the accompanying stretch in a material, he arrived at a wrong conclusion. Hooke's law, as we have adapted it and now use it, namely that stress is proportional to strain in a practically homogeneous structural material, within certain limits of stress, is itself an approximation, albeit a very close one, and on this law the whole mathematical theory of what we term the elastic behaviour of structural members has quite justifiably been built up. By relating this law to the law of the lever we can readily ascertain what must go on inside a simple rectangular beam of homogeneous material and can evaluate the beam's internal resistance moment or movement to the external bending moments or movements and ascertain the stresses in its fibres. But in addition to this equilibrium in rotation there is, *ipso facto*, an equilibrium in translation, up and down, for it is obvious that some tendency exists in the beam for one part to slide or shear past another, due to the weight tending to fall and the supports resisting that tendency through the medium of the beam itself. The question then arises as to how this shearing resistance is distributed, and again we have to fall back on the fundamental law of balance. We consider a small portion of the beam in the form of a minute rectangular prism as shown at "A" in Figure 1, and argue that it must be in a state of balance under all the forces acting upon it, as indicated in the figure.

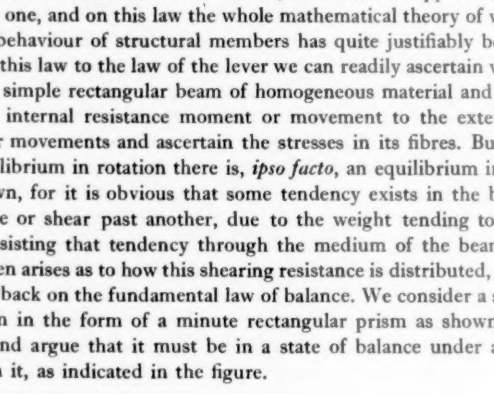

FIGURE 1

As logicians we see that all this must be so since the particle does not rotate, and then from these considerations we are able to ascertain the distribution of flexural stresses and shear stresses at all sections of the beam. Now this convenient division of the internal resistances into direct flexural stress and related

shear stress does not in fact exist in the beam but the complex combination which we have thus evolved from considerations of balance and Hooke's law gives rise to direct stress trajectories which arrange themselves as shown in the figure. These are known as principal stresses and indicate the distribution of tension and compression in every fibre of the beam in the plane of its elevation. This simple theory of homogeneous beams is then applied to the stress analysis of a very wide range of beam sections, from scaffold poles, tubes and rolled steel joists to built up plate girders and masonry dams, and is largely utilized for the design of heterogeneous beams, such as those of reinforced concrete; and its approximate accuracy, within the present limits of stress to which beams are designed, is such that no practical beam will evince signs of failure if designed to these principles. If we consider a welded plate girder, for example, we see that the principal stress trajectories as shown in Figure 2 indicate that the web of the girder is subjected to flexural stresses whereas it is a customary extended approximation to design the web for a uniform shear stress. In other words the girder is mentally divided into a web and two flanges; the former considered as transforming the vertical shear couples into horizontal resistances from the latter as shown in the figure.

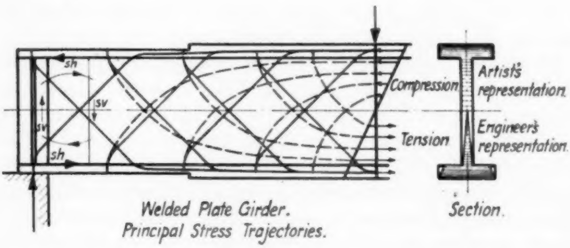

FIGURE 2

Now it is to be noted that this simple theory of the behaviour of beams and girders connotes some deformation, that is, bending of the beam, and it is common usage to compute this deflection from considerations of the direct flexural stresses only, ignoring the additional small deformation arising from the shear stresses. This brings in yet a further small approximation when applied to evaluating the resistances of the supports of a beam continuous over two or more spans, as it will be readily understood from Figure 3 that the relative deflection of the spans dictates the division of resistance between the supports and hence affects the whole design of the beam.

This, I hope, has shown up in an elementary form what we are up against in considering one aspect of the factor of safety and if time permitted we should see that these very reasonable and inherent approximations, which are necessary in order that the engineer can organize his work and keep it within reasonable bounds, attach to the whole of our working theories.

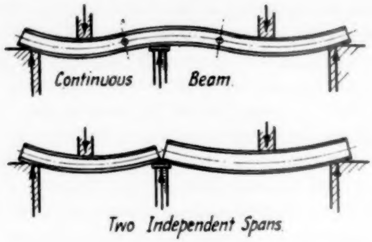

FIGURE 3

I mentioned earlier that the type of structure is significant in respect of the relationship of our theories to the factor of safety, and it will be remembered that all along I am supposing that materials and workmanship have an absolute reliability—a matter which I shall have to reconsider presently. Now there are broadly two main divisions into which we consider structures to be classed, namely, those of a trussed formation and those of a portal type, as shown, by way of example, in Figure 4. Structures in the first class are normally designed on the assumption that they have hinged joints so that the members of which they are comprised are free, theoretically, to compress or stretch and change in their angular relationship one to another. This assumption, which enables us readily to compute the forces acting along the members, by a simple application of the laws of balance, is again at variance with the facts, since the bolted, riveted or welded connections employed in the actual structures, together with the continuity which, for ease of fabrication and lateral stiffness, occurs in the case of members in line (as noted in the figure), produce resistances of a nature proper to the other divisions of structures, namely those of the portal type.

The portal structure depends for its stability on that very stiffness in the joints of its members one to another which is the disturbing factor in trussed types, and the relationship between the two classes is readily seen from the figure. The articulated truss is essentially a more economical type of structure than the portal, since the members in the truss are primarily subjected to direct axial forces which tend to utilize the whole cross section of each member, while the beam action which operates in the members of the portal is, as you have seen, limited by stresses at the extreme fibres of the members.

Now when the articulated structure is loaded, the tendency of the joints to rotate evokes a flexural resistance from the members by reason of the stiffness which the joints embody due to their practical construction, and this resistance, which is not taken into account directly in the process of designing the structure, has a complex relationship to the factor we are considering. On the one hand it gives rise to stresses in the joints and members in excess of those which the designer has calculated, but on the other hand it increases the sum total of energy which the load evokes from the structure in the process of deforming it. It also alters some of the assumptions upon which the individual members

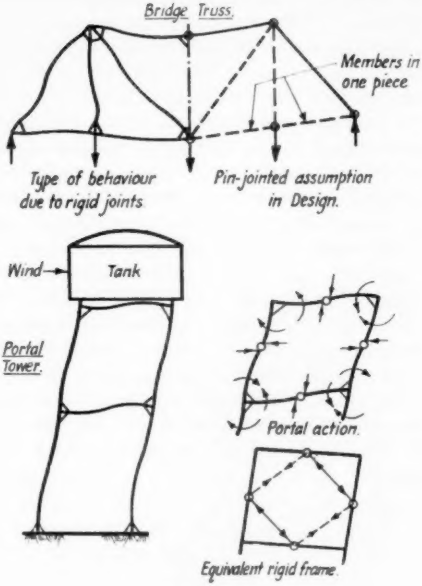

FIGURE 4

have been designed, especially in respect of the strut members, which, considered as functioning like pin-ended or partially constrained struts, are found to be suffering " S " bending. These secondary conditions due to joint stiffness are kept within certain bounds of probability by further approximate rules based on considerations of the flexural stiffness of the members in the plane of the truss, but the exact relationship to the factor of safety is obscure in any particular case. It is, however, probably on the side of safety, that is, we have a credit balance in most instances. To design a truss, *ab initio*, by strain-energy methods, which take all this into account, is a very lengthy business, involving trial and error procedure which is quite uneconomical from the common designing angle but which could be justified in cases where some hundreds of trusses were required to one standard; but the strain-energy theory itself embodies assumptions which are but close approximations to the truth, and in consequence our approach to perfection would only be relative.

We therefore see that we cannot find out by our normal analytical methods exactly how much we may have in hand in a trussed structure designed on a stress basis, that is to say that if we choose stress limits of a fraction of the stress at which each individual type of member composing the truss would be likely to start failing, we could not be sure that this fraction would be mirrored in the

structure as a whole. It is probable, however, as I mentioned previously, that the value would be on the credit side.

What I feel is needed to enable us boldly to sail nearer the wind, supposing that to be desirable, is not so much a deeper prosecution of analytical methods but a systematic empirical investigation of all our structural problems, instituted for the purpose of checking and amending those quasi-rational approaches which we find convenient to use in ordinary commercial design. This would I think enable us to retain our general methods and heighten our working stresses towards a closer approach to an absolute factor of safety, so that we might know with certainty that if we worked on stresses of a high percentage of the yield stresses we should still retain just enough in hand to meet the contingencies of imperfections in materials and workmanship. We noted that the fortuitous interdependence of members in trussed construction is the very basis of the functioning of portal construction and that something which is an adjunct in the one case becomes the primary consideration in the other; but more than this we know, due to the epoch-making researches of Professor F. J. Baker of Cambridge, that the portal is inherently capable of more punishment than a truly articulated structure by reason of its flexural continuity and its propensity to re-accommodate itself to a stress distributed in a way compatible with its maximum efficiency.

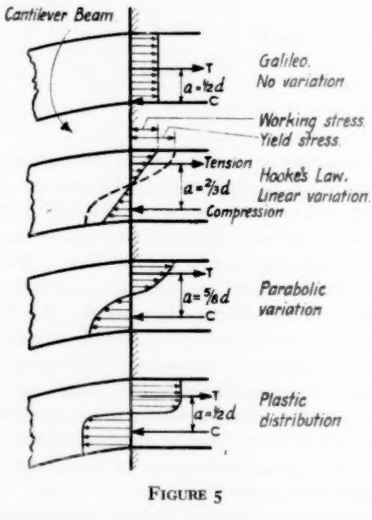

FIGURE 5

In general, we see that those rational hypotheses which have been found convenient for rapid use in design tend to evolve structures which embody a degree of ultimate resistance which is greater than that represented by the factor (itself approximate) which is implicit in our normal analytical approach

along the general lines of rigid body statics and the theory of elastic deformations, provided always that the structure does not embody any features which are erroneously conceived. We see for example in the trussed structure that the inherent rigidity of joints tends to give a multi-portal action which is an addition to the action of an articulated frame and that in the portal itself accommodation takes place. This accommodation arises from the phenomena which occur after the flexural stresses, which we considered earlier, pass from those complying approximately with Hooke's law to those which occur when the plastic range is approached. These phenomena, clearly illustrated in Figure 5, indicate how a member in flexure can develop a static resistance greater than that represented by the proportional stress increase relative to the usual elastic hypotheses on which beams are ordinarily designed, and when it occurs by self-selection in a rigid portal, re-distributions of stress are called forth and produce the maximum efficiency of the structure. We cannot go into the mathematics of these phenomena in this short lecture but suffice it to say that there is nothing new under the sun and we have known for a century that the modulus or measure of rupture of a rectangular beam is advantageously disproportionate to an ultimate strength based on Hooke's law, indeed we see that it would be illogical to suppose otherwise.

And this brings us to the crux of the matter, namely the substitution of a load factor for a stress factor as a basis of design. In the one case we decide on some fraction of the yield strengths of the material and design the structure in accordance with the laws of elasticity, supposing that the structure would just begin to evince signs of incipient failure if the loads and forces which it has been designed to carry were increased by the amount which the safety factor represents; and in the other, from a knowledge of what ultimate loads and forces inter-related structural members of various sectional forms and types can take, to design on the phenomena of incipient collapse, and apply a safety factor to that.

This latter method is at present in its infancy in so far as general design is concerned, and its protagonists are working hard to develop its fundamentals into a *modus operandi* which the practising structural engineer can use universally. It is not possible to go into the pros and cons of the matter in a lecture of this nature, but for my own part I incline to the view, at present, that the plastic approach will make its greatest contribution as a means of informing us as to what encroachments, if any, we can make on the present factors of safety in structures designed elastically. In this connection it may be conceded that a structure in use must be relied upon to respond elastically where fluctuating loads and forces are to be sustained, even if it may adjust itself plastically in the initial process of settling down to its job; and when we bear in mind the vast literature which has grown up around the elastic conception of the behaviour of structures and the experience based on this, which constitutes the mental approach of the practising engineer, it is borne in upon us that a change can only be the outcome of slow evolution and further experience.

So far we see therefore that some small factor must be used in connection with our design methods as such, and that the precise value of this factor is rather

indeterminate and variable, and we must now consider a number of other factors which have to be taken into account relating to materials, workmanship and variations in loading.

We may enumerate the categories to be insured against as follows, namely:

1. Those fundamental limitations in our theoretical approach which I have already touched on;
2. Approximations of weights and other forces;
3. Approximations and errors in the computation of loads and forces;
4. Approximations in assessing the conditions under which parts of a structure interact one with another;
5. Approximations and errors in mathematical computations;
6. Faults in materials, and
7. Faults in workmanship and erection.

All of these must be taken into account as items which it would be foolish to leave out of our reckoning as guarantors of public safety, and the intrinsic difficulty is to know what precautionary value to attach to each. We have found from a wealth of experience that working on the elastic basis of deformations and using design stresses which are some 60 to 70 per cent of the yield stresses of the materials, that signs of failure are not apparent; in other words that an elastic-stress margin of round about 35 per cent covers all the above items. This gives us a round average of 5 per cent error in each category and this is seen to be a reasonable margin in such an item as (3), in which a load computed as 100 tons might, in reality, be 105 tons; but when we come to item (4) the faculty of judgment might quite likely have a stress implication considerably in excess of 5 per cent. Such an excess could arise from an incomplete investigation of the degree of restraint at the ends of a strut, whereby the virtual length of the strut is taken at too favourable a value, or in a neglect of some secondary effect arising from the eccentricity of a joint, and such like; but these are matters which come within the preview of what we term good design and should not encroach much on their assigned safety factor in the hands of an experienced designer. By collecting information on the degree of ascertainable errors of approximation in a wide range of workaday designs it would be possible by the theory of probability to place a value on this factor instead of lumping it in with the general items, and in my view this would be a worthwhile task and one which would yield useful results.

Approximations in mathematical computations should be amply covered by the mean 5 per cent and leave a margin to allow for small errors which cannot be ruled out entirely in the practical business of computing literally thousands of values, and this is an item which could likewise be made the subject of a probability investigation.

And lastly we come to faults in materials, workmanship and erection. Structural materials, controlled, as they are, by many British Standard Specifications, which include a full gamut of tests, are manufactured to very dependable limits, and in the case of mild steel, for example, serious faults in the manufactured structural sections as delivered to the fabricating shops are not common and

are generally easily detected. The variations in sectional dimensions of hot-rolled shapes may be appreciable, according to whether the rolls in the rolling mills are new or worn, but these variations tend to be controlled by the weight tolerances which are operative as between the purchaser and manufacturer and by the desire of such persons as the works manager to avoid those troubles in fabrication which arise from such variations. A $\frac{1}{4}$ in. slackness in depth in a rolled steel joist of 8 in. deep would, other sectional dimensions being equal, cause a loss of flexural efficiency of about 5 per cent, and here again we could arrive at lower limit values which could be used as definite reduction factors. And then faults in workmanship must be reckoned with. These are of two kinds, one being imperfections inherent in the usual shop practice—in the machines used--and others due to sub-standard work. It must be remembered that the shop processes in a structural steelworks are not of the precision type appropriate to mechanical engineering and that tolerances in fitting are rather in the realm of hundredths than thousandths of an inch. Members deemed to be straight may be somewhat in winding and the fit of one part to another may not be dead true. Strains may be induced in the process of riveting or welding up the structures, and in general the average shop practice will be below what I might term Exhibition Standards. Holes out of alignment, loose rivets and imperfectly abutted parts are faults amenable to routine inspection and remedial measures, and in general the average standard is as high as the nature of the work permits; but some of these faults are liable to aggravation in site erection where plumbing and alignment and the riveting or welding of joints may have to be done during unfavourable weather conditions and from scaffolding or slung cradles. Again, we can only surmise that the 5 per cent which our factor may be considered to include in order to cover the effects on stress which these items connote, is adequate to cover all cases.

We may now return to our first consideration of the essential approximations in theory and note that, in relationship to shop practice and the design of details, a number of further approximations are involved which affect stress distributions. These are chiefly related to stress variations in the region of rivet and bolt holes, which are not separately taken into account, whereby in parts in compression and shear the gross un-holed section is assumed and in parts in tension the stress is taken as uniform over the nett section. In structures primarily subjected to static loading two well known but practically indeterminate conditions are included in this respect, namely, the stress concentration at the margins of holes in tension members and a similar concentration of bearing stress assuming bearing to take place at the periphery of bolts and rivets; but in structures subjected to continual stress variations such as bridges, the effect of these "stress-raisers" on fatigue is being given close attention, and design stress reductions are recommended in relationship to the number of stress cycles and the range of stress variation, whether a change of stress of the same kind or a reversal of stress ranging between tension and compression.

These fatigue considerations become much more important in welded structures due to the greater rigidity of welded joints in comparison with riveted

ones, and greater experience is needed before the effect of these things on the factor of safety can be determined with more certainty.

When we weigh up the whole of the evidence which I have briefly put before you in this short lecture, it is I think evident that, bearing in mind the practical aspects of the business of structural engineering, the margins of safety at present approximate to a limit beyond which it would be imprudent to pass without a systematic stock-taking of where we stand. As I hinted earlier, it is my view that what is wanted is not so much a continual prosecution of analytical methods for the purpose of ascertaining absolute values satisfying the dictates of strict scientific enquiry but a thorough programme of tests framed to check the margin between working loads and the onset of progressive failure in all kinds of structural members, and indeed complete structural frames, calculated, designed and fabricated to the standards which at present answer our purpose.

This is no easy matter and would need the full-time attention of a complete staff of practising engineers, physicists, mathematicians, computors, laboratory assistants and mechanics, and would entail a large expenditure over a number of years; but I am convinced that such a set up would bring very fruitful results and settle many of our queries. In order to make clear the distinction which I have in mind let me, in conclusion, instance a specific case.

A strut composed of two main members battened together is one of the most mathematically indeterminate parts of a structure but one which, with the increasing application of welding, will I think tend to be more and more employed. Its analytical complexity arises from an aggravation of the already rather complex nature of strut behaviour in general (a matter which could occupy us for several hours this evening), and it is hardly possible to devise a rational fundamental formula which would be of direct service in design. In consequence we fall back on certain quasi-rational rules of design, devised from more or less strict analyses, tempered by practical dictates, which enable us to arrive at the cross-sectional dimensions of the strut by analogy with a normal strut, now what is needed is a comprehensive series of tests covering the whole practical range of such struts with variations of batten sizes and spacing devised to ascertain the limits of validity of the rules and such variants as could be permitted in certain circumstances. Such an investigation would produce the kind of information the practising engineer is wanting and would be a valuable contribution to the solution of this important factor which has engaged our attention this evening—I am glad to say that limited work along these lines is now proceeding.

I have not considered any margin for accidental overloading either due to inordinate stacking of materials during the construction of a building or due to overcrowding or vehicular accidents on the finished structure, nor for deterioration due to corrosion, but a well-designed structure will take some such punishment and can be inspected and remedied subsequently—but this again has a bearing on the safety factor.

I hope this rapid survey of what we are up against in seeking to improve structural efficiency in the interests of getting full value for our money will stimulate the kind of research I have advocated.

II. FAULTS AND IMPROVEMENTS IN METALS

by

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The factor of safety to be employed in any given structure is a matter for the engineer alone. Any attempt by the metallurgist to override the results of experience would be presumptuous, and I have no intention of entering into this field. Where the metallurgist can be helpful, however, is by indicating possible sources of increased strength in engineering materials, and by this, without any modification of such factor of safety as the engineer may deem necessary, to obtain the given strength in the structure with smaller sections and therefore with economy in material. This is what I hope to attempt this evening.

To try to discuss all the metallurgical problems raised by the title of this lecture in the time available would be to attempt the impossible, and I shall, therefore, confine my attention, in the main at any rate, to the ordinary constructional steels used under conditions such that the service stresses are essentially static. Further, my chief object is to raise some points of immediate, practical interest both to the engineer and to the metallurgist, rather than to attempt to provide answers to these questions, that is to bind on other men's shoulders burdens not too heavy, one hopes, for either the theorist or the technologist to bear. It must not be assumed, however, that these suggestions are new; most, if not all of them, have received and are still receiving the close attention of both the metallurgist and the engineer. All that I can do here is to try to focus attention on what seem to me to be the more important spots.

All attempts to estimate the theoretical strength of metals have suggested figures enormously higher than those in fact found. An explanation of this has been sought by invoking internal defects in the crystals which may act as cracks or points of stress concentration. The insuperable difficulty, however, of accepting this suggestion, or so it appears to me, seems to lie in the fact that, whenever special care is taken to produce a metallic crystal in its most perfect form, as, for instance, by prolonged annealing and slow cooling, the strength of the crystal, so far from increasing as the theory would seem to demand, is lowered considerably. It appears, therefore, that we are compelled to accept the view that it is the theoretical treatment itself which is subject to defects, and that there is at the moment little or no possibility that the very high strength which has been suggested theoretically can, in fact, be hoped for.

CAUSES OF FAILURE

It may be well to commence this discussion by a review of some of the reasons why failures do occur in metals.

So far as static stresses are concerned, and dynamic ones involve complications too great to be dealt with in a single lecture, it is usually found that failures of engineering parts can rarely be ascribed to any single cause, but are the result of a combination of additive factors. Direct overstressing is in fact uncommon—except in those cases where it is known to occur and has been allowed for in the design. The most dangerous single stresses are almost invariably tensional, a fact which is perhaps not unexpected, since such stresses will tend to open out cracks once they have started. This is in agreement with, for instance, the work of Bridgman[1], where samples which have been stressed under high hydrostatic pressure show increased strength, and often a most spectacular increase in ductility.

Stress concentration must result from all structural discontinuities within the material, from inclusions or from inhomogeneity of composition or structure, and leads to highly localized internal stresses, called by Lazlo[2] "tessellated". The exact effect of such structural stresses still appears to be somewhat uncertain, though it may be great. There can be no doubt, however, that inclusions can, and not infrequently do, have a most pernicious effect by acting as stress raisers and the starting points of cracks.

At the free surfaces, the three-dimensional stress system which pertains to the interior, gives place to a simpler, two-dimensional one, and there is good evidence for the belief that such free surfaces can be locations of considerably reduced strength. No better evidence of the influence of these free surfaces can be desired than that provided by Edwards and Pfeil[3] during their investigations which led ultimately to the production of single crystals of iron by the stress-anneal technique. The effect just considered is the immediate result of the absence of normal stresses at the surfaces, and is independent of other reasons for superficial weakness, such, for instance, as decarburization, the harmful effect of which on the fatigue strength of a part has been more than adequately demonstrated.

Bad design, in many cases due to too rapid a change of section, by setting up stress concentrations may lead to unexpected failure, but such cases should in the main have been foreseen. Brearley[4] has pointed out that the engineer himself, by insisting on the stamping of parts for the purpose of identification, is responsible for the deliberate production of notches from which failure can, and does, commence. That such marking should be reduced to a minimum, and even then made on those surfaces of a part on which it will have the least harmful effect, is self-evident. Rough machining, by tearing the surface, is another possible source of failure[5], as are all surface irregularities, rokes, laps, etc.

Although the engineer's factor of safety is designed to allow for these and similar conditions, the simultaneous occurrence of two or more may not be adequately covered, and it is then that failure will take place.

Quite apart from the actual loss of metal, the rusting of steel is highly detrimental in the formation of pits which act as points of stress concentration, in

the embrittlement of the material, due possibly to the occlusion of hydrogen, and, under conditions leading to fatigue, in the rapid acceleration of this process. Moreover, since the volume of the rust formed is roughly four times that of the steel from which it was produced, the corrosion leads to a considerable expansion, thus setting up stresses which may be sufficient to shatter rivets or crack concrete cladding.

Whether the full effect of the rate of loading has as yet been completely elucidated may be a matter of opinion. There is good evidence, however, which suggests strongly that the total energy absorbed in, for instance, the Izod test (and it should be remembered that all engineering materials are in fact notched to a greater or less degree) is actually higher in impact than during slow bending. This fact gives rise to the obvious question as to whether shock stresses are, in fact, so particularly dangerous, and there would appear to be a still incompletely explored field of research to provide once and for all a clear answer to this most important question.

Service stresses may be highly complex, and another question to which, at any rate in my opinion, no completely satisfying answer has as yet been given, is the extent to which the mathematical treatment of complex stresses, particularly in the plastic range, is to be relied on in practice. There is still much experimental work to be done before the importance of the simplifications necessarily employed in the mathematical treatment can be adequately assessed.

May I give an example, even at the risk of revealing my own pig-headedness? It is agreed that a simple tensile stress may be resolved into a shear stress and a second tension normal to the shear plane. On the basis of the atomic structure of metallic crystals, I am by no means convinced that the normal tension across the surface can be neglected, as is often assumed, despite the evidence—meagre in my view—which appears to support that belief.

At elevated temperatures the microstructures of alloys may often show marked signs of instability; the breakdown of laminated pearlite to the globular form is an example. Such changes may cause serious weakening or, particularly in the lower temperature range, definite embrittlement. In iron, at temperatures not very much above that of the room, abnormalities in mechanical properties, such, for instance, as the modulus of rigidity or the limit of proportionality in torsion, have been observed by many workers[6, 7]. How far such abnormalities may be responsible for failures at temperatures between that of the room and, say, 250°C. is uncertain, but the possibility at any rate does arise. There are a number of corresponding examples, of as yet unknown origin, in which even a single phase may show marked variation in properties over a certain temperature range. The low-notched bar values found in the α-phase of the brasses between about 350°C.–650°C. (Table 1) afford an example, regarding the explanation of which there is, so far as I am aware, nothing even to suggest where the cause is to be sought.

Improvements in the mechanical properties of steel may be effected by changes of composition, or of heat, or by mechanical treatment, and these will be considered in turn.

TABLE I

EFFECT OF TEMPERATURE ON THE TOUGHNESS OF 70 : 30 BRASS

Temperature °C.	*Impact Value ft./lbs.*
15	44
300	32
350	6
500	6
600	6
700	11

IMPROVEMENT BY CHEMICAL MEANS

So far as improvements due to changes of composition are concerned, an unhardened steel consisting of ferrite and carbide may be modified by the addition of alloying elements which are held in solid solution in the ferrite on the one hand, or which, alternatively, pass into the carbide. There is little evidence to suggest that variations in the composition of the carbide do of themselves exert any measurable effect on the ordinary mechanical properties, and it is, therefore, to the composition of the ferrite that our attention must here be directed. A solid solution in iron, as of course in any other metal, may take place either by substitution of iron atoms for others of manganese, nickel, cobalt, etc. where the atoms are similar in size, or, on the other hand, by interstitial solid solution in the "holes" between the iron atoms where the alloying element is one whose atomic size is relatively small, e.g., carbon, hydrogen nitrogen or boron. In the steels both forms of solution may occur simultaneously.

The time will come, possibly in the near future, when the internal stresses due to the degree of lattice distortion, and therefore the hardening which results from such substitution or replacement, may be calculated, and the alloying of steel will then be placed on a truly scientific basis, but that day has not yet dawned.

It is a curious fact, and one which seems to be a general phenomenon in metallurgy, that a greater hardening effect is obtained when small proportions of a large number of different elements are dissolved than when the same total amount, even of the most efficient of these, passes into solution. The high tensile gold alloys and the complex steels used for tools or for high temperature service illustrate this fact equally. So far then as ordinary steels are concerned, it would appear that a very large field of investigation, at the present time inadequately explored, is that of the simultaneous addition of many elements, nickel, chromium vanadium, copper, molybdenum, aluminium, etc., all in small amounts, of the order of a fraction of one per cent. The simultaneous effects of hydrogen, nitrogen and boron in even smaller amounts could well go side by side. In this connection it may be noted that as time goes on, the tendency for the average steel to contain greater and greater percentages of "residual" elements increases,

and the time has already come when it would repay much work and trouble to inquire how far these, instead of being regarded merely as nuisances, can be turned to good account in raising the strength of the everyday steels.

As the carbon content of an unhardened steel increases so, of course, do the elastic limit and the tensile strength. Simultaneously the ductility tends to fall. Where the material is to be subjected to service under stresses which are essentially static, the question inevitably arises as to whether the steels employed at the present time are not of unnecessarily low carbon content; in other words, whether it is necessary for the engineer to insist on such high values of the elongation per cent and reduction of area as he does at the moment. This is clearly a matter for the engineer himself to decide, but if he could satisfy himself that, at any rate in many cases, existing specifications do demand a higher ductility than is in fact necessary, higher carbon steels, of increased strength, could be employed, and a corresponding saving in the tonnage used be effected.

Even with a carbon content as high as 0.45 per cent together with a manganese content of 0.78 per cent, $1\frac{1}{8}$ inch diam. bars normalized at 870°C. give the following test figures:

Yield Point	27 tons/sq. in.
Maximum Stress	44 tons/sq. in.
Elongation per cent on 2 inches ...	27
Reduction of Area per cent	54
with an Izod Value of	31 ft./lbs.

It is difficult to believe that such a steel does not possess both a sufficient ductility and adequate toughness for most normal constructional requirements.

Such higher carbon steels might present somewhat greater difficulties in production and manipulation, but these are not insuperable if the increased strength is deemed justifiable.

The time, too, has surely come when the question of the reliability of the higher manganese steels should be settled once and for all. There is sometimes a feeling that such steels, with a manganese content between perhaps $1\frac{1}{4}$–2 per cent are "uncertain", but the evidence for this is by no means conclusive. May I quote here at length from Bullens' well-known book[8]? "It has been difficult for the carbon-manganese structural steels to live down their previous bad name for being 'brittle'. The author has not changed his opinion, expressed in the previous edition of this book, that the carbon-manganese steels are not brittle. In fact, he now believes it logical to eliminate (even) the word 'sensitive', then applied. With proper control of heating, forging, and finishing temperatures, and saturation on heating for hardening, followed by a rate of cooling denoted by carbon-manganese content in relation to the mass-surface factors, these steels are no more sensitive than the other alloy structural steels, and, in fact, less sensitive than some". "The evidence at hand to date warrants the statement that, for many structural and engineering purposes, these carbon-manganese steels are vastly superior to carbon steels . . . . and they are equal to, or better than, many low alloy steels". "Normalized carbon-manganese steels are better

than normalized chromium-molybdenum steels". But "it is not to be inferred from the above that the carbon-manganese steel is the 'one, all-purpose' steel, for such is not the case; but it is a low-price steel suitable for many purposes and its value is not generally recognized."

Typical figures for steel containing 0.3 per cent carbon and about 1.6 per cent manganese, normalized at 900°C. and tempered at 400°C., even in the as-cast condition, were as follows:

Yield Point	29 tons/sq. in.
Maximum Stress	45 tons/sq. in.
Elongation per cent on 2 inches ...	20
Reduction of Area per cent	39
with an Izod Value of	39 ft./lbs.

There is nothing here to suggest anything dangerous. Such a test in fact suggests a material of thoroughly good properties.

Such steels in the higher manganese range are of higher hardenability than those at present normally employed, and certain modifications in practice may be required, but these modifications, if required, could be made without any undue difficulty.

TABLE II

EFFECT OF PHOSPHORUS ON THE TENSILE PROPERTIES OF A 0·3 PER CENT CARBON STEEL, AS ROLLED (STEAD)

Phosphorus per cent	*Yield Point tons/sq. in.*	*Maximum Stress tons/sq. in.*	*Elongation per cent on 2"*	*Reduction of Area per cent*
0·04	20	33	23	52
0·3	25	40	23	45
0·5	32	44	20	45

Another, and very much more controversial, question arises with regard to the phosphorus content to be permitted. That the yield point and tensile strength of a mild or medium carbon steel in the unhardened state increase with the phosphorus is well known—Table II. That the ductility falls, but at no particularly alarming rate, has been shown by Stead so far as straightforward tensile properties are concerned. There is, however, the belief, for which a considerable body of evidence exists, that steels of high phosphorus content may fail by brittle fracture when subject to shock, and that such steels are inherently "wicked". A good deal of work has been done on the effect of phosphorus, particularly on low carbon material. Micrographically it results in the grain size becoming coarser for a given heat-treatment and along with this an increased tendency for brittle, cleavage fracture. There are, however, other elements, aluminium for instance, the effect of which on the structure of the steel is in the opposite direction, resulting in a finer grain size, and investigation regarding the possibility of obtaining adequate ductility and toughness in steels of distinctly higher

phosphorus content than those now employed which also contain small amounts of other elements, would appear to be among the most promising of empirical investigations. It is not suggested that these ideas are in any way novel. Gillett[9], for instance, as far back as 1935, and many others have already discussed the problem, and Andrew and Swarup[10] have particularly indicated the beneficial effect resulting from the addition of 0.2 per cent aluminium to structural alloy steels of high phosphorus content, but they have been voices crying in the wilderness. As examples of the tensile properties which can be obtained from high phosphorus steels, a few typical results given by Jones[11] are recorded in Table III.

TABLE III

MECHANICAL PROPERTIES OF SOME HIGH PHOSPHORUS, LOW ALLOY STEELS

Composition per cent				*Normalizing Treatment*	*Yield Point t./in.²*	*Maximum Stress t./in.²*	*Elongation per cent on 2"*	*Reduction of Area per cent*	*Izod Value ft./lbs.*
C	*Mn*	*P*	*Alloy Elemenst*						
0·10	0·30	0·19	—	920°C.	24	32	36	68	79
0·17	0·30	0·18	—	900°C.	28·6	35·4	33	59	26
0·25	0·30	0·11	Cu 0·4	880°C.	28	37	31	57	40
0·08	0·30	0·21	Cu 0·96	—	29	34·5	33	66	52

It must, however, again be emphasized that this discussion is restricted to ordinary structural steels statically loaded. Where fluctuating or shock stresses may be imposed, any marked increase in the phosphorus content, on the evidence at present available, would be highly dangerous, as would be the presence of high phosphorus in steels of higher carbon content.

I may perhaps be permitted also to discuss the effect of sulphur, though this is in the main economic. As is thoroughly well known, provided that the manganese content of the steel is sufficiently high, the sulphur exists almost entirely as a complex iron-manganese sulphide out of solution. As a result of the forging operations, this sulphide is drawn out into threads, and then, as Brearley emphasized long ago, exerts an influence neither greater nor less than that of any other inclusions, such as silicates. It seems difficult to understand why the sulphur content should be so strictly controlled when other non-metallic inclusions are taken more or less for granted. So long as the stressing is longitudinal the effect of the sulphur is almost non-existent, though the transverse ductility and toughness may be considerably reduced. Brinell, many years ago, showed that even ½ per cent of sulphur in the presence of 1 per cent of manganese gave a material with adequate tensile properties, and which presented no special difficulty in production. More recently confirmation has been obtained again on a steel containing 0.5 per cent of sulphur, the mechanical properties of which,

taken from the centre of the ingot and after a forging reduction of 16.1 were as follows:

	Yield Point t./sq. in.	*Maximum Stress t./sq. in.*	*Elongation per cent on 2 inches*	*Reduction of Area per cent*	*Izod Value ft./lbs.*
Longitudinal ...	17	24	38	58	51
Transverse ...	12.4	13.2	3	11	18

The properties in the longitudinal direction seem entirely adequate, whilst the remarkably poor tensile properties in the transverse direction afford a most valuable warning, which is of general application, against over-working a steel when it is subsequently to be stressed transversely.

There is some evidence to suggest that the corrosion resistance of high sulphur steel is rather lower than that of normal material, but it certainly seems to be a case of straining at a gnat and swallowing a camel, to reject an otherwise perfectly satisfactory steel because its sulphur content slightly exceeds an, in my opinion, unnecessarily low specification value.

Although the major portion of the carbon content of a soft steel exists in the pearlite as iron carbide, since ferrite at room temperatures has a negligible solubility for this element, this solubility may reach a figure of the order of perhaps 0.025 per cent just below the carbon change point. Further, it has been suggested by Benedicks[12], and even if his conclusions have not been confirmed they have not, so far as I am aware, been refuted, that the iron phase of the pearlite may contain carbon in solid solution in concentrations much greater than that which is present in the normal ferrite. When the pearlite becomes sorbitic and then troostitic, the corresponding increase in the electrical resistivity suggests more than strongly that the iron matrix is holding a still higher concentration of carbon in solution. This conclusion is in complete accord with the well-known physical-chemical fact that the solubility of a material increases as the particle size diminishes. It would appear at any rate not impossible that the increased strength of a steel in the sorbitic and then in the troostitic states is, as I think, due not so much to the increasing fineness of the state of dispersion of the carbide, as to the fact that this carbide is immersed in a matrix which itself is of a progressively higher carbon content. Not only does the solid solution of carbon in α-iron increase the hardness, but it may also lead to age-hardening phenomena which raise the strength still further, and quench-ageing low carbon steels, that is ageing after a quenching operation from a temperature below the A_1 point, despite the work which has already been done, eminently justifies further investigation.

Another element which causes age-hardening effects in steel is copper, and Table IV shows the increased strength which can be obtained in an 0·3 per cent carbon steel (as cast) due to the presence of 1·2 per cent copper. In order to get such hardening, the minimum content of copper or other alloying element

must be above the limit of solid solubility, and in this case about 1 per cent is required to provide an appreciable hardening effect. By the simultaneous addition, however, of other metals in solid solution the solubility of the age-hardening element may be reduced, and corresponding effects, therefore, obtained at lower concentrations. Since at any rate in certain circumstances copper also reduces corrosion, it would appear that investigation from the age-hardening point of view of copper steels containing small amounts of several other elements might be profitable.

TABLE IV

AGE-HARDENING EFFECTS OF COPPER ON A CAST 0·3 PER CENT CARBON STEEL

Cu per cent	*Normalized at 900°C. and Precipitation Hardened 3 hrs. at 500°C.*				
	Yield Point tons/sq. in.	*Maximum Stress tons/sq. in.*	*Elongation per cent on 2 inch*	*Reduction of Area per cent*	*Brinell Hardness No.*
0	26	42	14	22	175
1·2	39	53	10	15	230

Nitrogen, even in the amounts normally present in steels, is known to exert a considerable effect in enhancing strain-ageing. It may unfortunately, however, result in most serious embrittlement, and a field of fundamental research which calls for urgent examination is the full story behind the brittleness of materials which are normally ductile. The main difficulty in increasing the strength of engineering materials lies, indeed, in the fact that although this hardening can be effected without difficulty, it is in so many cases associated with a more or less marked embrittlement. A complete understanding of the reason for the brittleness should enable increased hardness and strength to be obtained without what is, at present, the insuperable drawback of inadequate ductility.

It has already been pointed out that surface decarburization may exert serious effects on the mechanical properties, especially under conditions which may lead to fatigue. Mild carburization of hot-worked or heat-treated material, by eliminating the weak ferritic surface, should produce material the mechanical strength of which is substantially higher. Such carburization need not be very uniform, and it should be possible to effect it during production by incorporating a simple carbonizing enclosure in the cooling, say, from the rolls.

It has been estimated that in Great Britain alone the total annual cost due to corrosion is now of the order of £200 million, and the detrimental effects on the steel itself have already been mentioned. The British Iron and Steel Research Association has recently published a most interesting little brochure[13] outlining some of the practical conclusions reached by its Corrosion Committee. Rusting may be prevented, or at any rate retarded, by the addition of inhibiting reagents in the corrosive medium; by modification of the design by reducing the danger of moisture lodging in the structure; by changes in the composition of the steel

and by efficient protective measures, including painting, the use of metallic coats and cathodic protection. Relatively inexpensive low alloy steels containing small percentages of chromium and copper may be three times as resistant as ordinary mild steel under atmospheric conditions, and it is justifiable to enquire whether sufficient use is made of such material in this country. Zinc is probably still the best all round metallic coating for steel, though sprayed aluminium coats about 0.004 inch thick, under normal conditions of rusting, give almost as good results, whilst in contaminated, industrial atmospheres lead coatings have proved useful. Cathodic protection, particularly of underground structures, is being increasingly adopted; the process consists in making the steel the cathodic element in an electrolytic cell, the protection being obtained at the expense of auxiliary electrodes, such as magnesium alloys.

IMPROVEMENT BY HEAT-TREATMENT

The subject of improvements in the mechanical properties of steel by structural changes due to heat-treatment is so vast that only two aspects can be dealt with here.

The importance of the crystal boundaries in determining the strength and ductility of a metal is generally appreciated, though it may be legitimate to point out that certain researches which suggest variations in the strength of the boundary may in reality be due to simultaneous changes which have been effected in the crystals themselves, as a result of the heat-treatment required to produce modifications of the crystal size. We know, in fact, very little about the crystal boundary and much recent theoretical work is based on assumptions which at the moment are pure speculation.

In this connection it may be pointed out that the idea of certain theorists that the crystalline structure extends more or less unchanged up to the very edge of the grain, and is almost immediately replaced by that of the new crystal, is pure assumption, unsupported by a vestige of evidence. It is equally true that Humfrey's hypothesis[14] that at the boundary there is a quite gradual swinging over from the orientation of one crystal to that of its neighbour is similarly unsupported.

What then is the "thickness" of the boundary An answer to this question cannot be given. In the same way we know nothing about the effects, if any, of heat-treatment on these boundaries, and there is here a field of fundamental research of extreme importance.

Although, in general, the mechanical properties of an alloy improve as the grain size becomes smaller, there are exceptions. The small grain size steels obtained by controlled deoxidation with aluminium may give much higher Izod values than do coarser grained materials, but, most curiously, not infrequently a lower yield stress. A $1\frac{1}{8}$ inch bar of 0.35 per cent carbon steel with 1.4 per cent manganese and 0.2 per cent molybdenum, for instance, when oil quenched from 840°C. and tempered at 550°C. had a yield point of 65 tons/sq. in. in the coarse grained condition against only 54 in the fine grained state.

The improvement in the mechanical properties which can be effected by

isothermal transformations is too well known to need emphasis, but the question does arise as to the possibility of devising simple forms of heat-treatment of a similar isothermal nature in ordinary engineering sections. Interrupted quenching is no new process, but the application of some such process to ordinary structural steels during their cooling from the hot rolls offers an interesting field of study.

As an example of the type of simple isothermal transformation which I have in mind, the following may be taken as a general outline. If from the hot rolls the section be taken to the shears and then allowed to cool until a temperature of around 900°C. is reached, they could then be "quenched" by dropping into a pit in which the temperature is allowed to fall fairly rapidly to, say, 400°C. On attaining this temperature, and there is no need for it to be very accurately controlled, the lengths could be transferred to an isothermal furnace at a similar, or a slightly higher temperature, kept there for a period which will depend on the composition of the steel, but even with a manganese content as high as 1.8 per cent need not exceed, say, 15 minutes. The lengths could then be cooled in air and the steel possess a structure with less ferrite than that normally present, and a much finer, sorbitic, type of pearlite. There is nothing in such a scheme which need add substantially to the cost of the sections or interfere with the flow of the production.

Quite apart from the possibility of increasing the strength by producing a finer type of pearlite, rapid cooling results in the retention of some at any rate of the ferrite—the weakest constituent in the whole structure. Another aspect which should not be overlooked is that in steels of very low carbon content no quenching, however rapid, is sufficient to retain a fully martensitic structure, a not inconsiderable amount of ferrite always being precipitated. The martensite in such cases is itself, due to its low carbon content, relatively ductile, and being sandwiched in between the soft ferrite exerts a strengthening effect which is not associated with any serious embrittlement. Where such low carbon steels are employed, would it be improper to suggest the deliberate quenching, even in water, of the sections as they cool down from the rolls?

TABLE V

MECHANICAL PROPERTIES OF 0·17 PER CENT C, 0·72 PER CENT MN. STEEL BARS $1\frac{1}{8}$ INCHES DIA.

Treatment	*Yield Point t./in.²*	*Maximum Stress t./in.²*	*Elongation per cent on 2 inch*	*Reduction of Area per cent*	*Izod Value ft./lbs.*
Water quenched 920°C. ..	32	46	22	51	24
Water quenched 920°C. and then water quenched 760°C.	24	40	32	64	43
Oil quenched 920°C. ..	23	36	31	65	92

I have already asked the engineer to decide whether he really needs so high a ductility as is often specified. Another question, quite as important, is whether he needs all the toughness, i.e. Izod value, that he tends to ask for, a question which Dr. W. H. Hatfield asked many years ago

In the fully hardened, martensitic, state, the limit of proportionality of steel is very low; on tempering, this value rises up to about 400°C., in the case of plain carbon steels, when the structure has become troostitic, and then falls again. It is this troostitic structure then which possesses the highest ratio of elastic limit to tensile strength. In most cases, however, a sorbitic structure, obtained at a higher tempering temperature, is preferred, presumably on account of its much higher impact value. A steel of the composition: 0.26 per cent carbon, 0.30 per cent silicon and 0.75 per cent manganese in the form of bars $1\frac{1}{8}$ inch diameter, water quenched from 900°C. and tempered at 400°C. gave the following mechanical results:

Yield point	38 tons/sq. in.
Maximum stress	54 tons/sq. in.
Elongation per cent on 2 inches ...	15
Reduction of area per cent	44
with an Izod value of	26 ft./lbs.

Surely such a steel has both adequate ductility and toughness for many purposes despite its troostitic structure, and the high yield stress (for a 0.26 per cent carbon steel) should be undeniably attractive.

MECHANICAL IMPROVEMENT

The essential constancy of Young's modulus for steels of widely differing composition and treatment is well known. An increase of at least 10 per cent in this modulus may, however, be obtained by cold-work followed by "blueing", i.e. reheating to a temperature of the order of perhaps 300°C. This seems to be the only possibility available for increasing the modulus of elasticity, since alloying steel has normally little effect, and where it does exert an influence, this is frequently detrimental.

With regard to fatigue, all that can be said here is to draw a clear distinction between the initial crack due to the fatigue itself and the "creeping" crack which is then propagated due to stress concentration. The failure to distinguish between these two quite distinct effects has at times led to trouble. The fatigue limit is a function of the tensile strength, and fatigue proper is, therefore, diminished by the employment of a stronger steel. The creeping crack on the other hand is connected with the notched-bar toughness of the material, which tends in general to decrease as the hardness is raised, and there are well-known examples of the fact that failures ascribed to fatigue have been reduced by the employment of softer steels, of lower, instead of as would be expected of higher, strength.

The increase of strength and, when properly heat-treated, of the elastic limit in particular, resulting from cold-work, is well known. Whether, however, full advantage is taken of this fact by the structural engineer may be doubted. Particularly in the case of built-up structures, and provided that a lower ductility

than is at present demanded can be accepted, there would appear to be advantages in the use of cold-rolled sheets, provided, of course, that the material is not annealed during fabrication, for instance by welding. The importance of the ageing treatment, if such material is to be employed, is outstanding, and the following figures, due to Aitchison[15], on steel, of which the composition unfortunately is not given, Table VI, illustrate the order of the elastic limit which might be expected.

TABLE VI

EFFECT OF "BLUEING" ON THE PROPERTIES OF COLD-WORKED STEEL

Blueing Temperature	*Limit of Proportion-ality*	*Maximum Stress t./in.^{2}*	*Elongation per cent on 2 inches*	*Reduction of Area per cent*
Room Temperature ..	27	70	5	18
400°C.	51	73	9	37

The limit of proportionality immediately after working a steel, if there be such a thing at all, is of quite a low order. As the reheating temperature rises so does the elastic limit, up to a temperature in the region of 400°C. The tensile strength, however, remains little affected, and the proportion, therefore, of the elastic limit to the maximum stress rises very considerably. We are, however, up against the old difficulty that when the elastic ratio is a maximum, the ductility is often comparatively low; and even at the risk of harping again on the same problem, the time must come for the engineer to review the whole position regarding the essential degree of ductility required in statically stressed structures.

This lecture has consisted almost entirely of asking questions of the engineer, of the metallurgist and the theorist, and I am under no delusion in believing that I have been able to provide any answers to them. Of the engineer in particular the two outstanding points seem to me to revolve around the degree of ductility and toughness really required. If he could satisfy himself that at present he is asking for too much in both of these properties, the metallurgist would have no difficulty in providing him with material, still very far from brittle, and with greatly increased yield strength.

To many of the questions which have been asked an answer can clearly only be given after research, both technological and scientific, which will require years to reach completion. The issues involved are, however, so big that there ought, in my opinion, to be no delay in beginning to think about them and in planning the work on which most important decisions will rest.

The suggestions which have been made both for control of composition and of heat-treatment would inevitably lay extra burdens on the producers, and hence increase the cost of the material. It would be a matter, however, for the economist of the day to determine whether this increased cost was justified in view of the enhanced strength of the material, and therefore of the smaller sections which would be sufficient to perform the same service.

There is an old saying, in the north country at any rate, which is particularly applicable to this paper: "Any fool can ask questions which the wisest man cannot answer".

REFERENCES

1. *Bridgman, P. W.*: "Studies in Large Plastic Flow and Fracture," *London*, McGraw-Hill, 1952.
2. *Lazlo, F.*: Journ. Iron and Steel Inst., 1943, 147, 173; 1943, 148, 137; 1944, 150, 183 and 1945, 152, 207.
3. *Edwards, C. A.* and *Pfeil, L. B.*: Journ. Iron and Steel Inst., 1924, 109, 129.
4. *Brearley, H.*: "The Heat Treatment of Tool Steel," *London*, Longman, 1916, 136.
5. *Brearley, H.*: "The Heat Treatment of Tool Steel," *London*, Longman, 1916, 63.
6. *Lea, F. C.*: Engineering, June 30, 1922.
7. *Goffey, A.* and *Thompson, F. C.*: Journ. Iron and Steel Inst., 1923, 107, 465.
8. *Bullens, D. K.*: "Steel and Its Heat-Treatment," 3rd ed., *London*, Chapman & Hall, 1927, 350.
9. *Gillett, H. W.*: "Iron Age," 1936, 137, 42.
10. *Andrew, J. H.* and *Swarup, D.*: Iron and Steel Inst., 1st Rep. Alloy Steels Res. Cttee., 1936, Sect. XII, 227.
11. *Jones, J. A.*: Journ. Iron and Steel Inst. 1937, 135, 113.
12. *Benedicks, C.*: Doctorate Thesis, University of Uppsala, 1904.
13. *The British Iron and Steel Research Association*: "The Fight against Rust," 1952.
14. *Humfrey, J. C. W.*: Journ. Iron and Steel Inst., Carn. Schol. Mem., 1913, 5, 86.
15. *Aitchison, L.*: "Engineering Steels," *London*, MacDonald and Evans, 1921, 268.

GENERAL NOTES

THE ROYAL ACADEMY

The Royal Academy is almost bound to be an average show. Many artists are not good enough to have their work accepted by the R.A., and many distinguished artists do not submit their work. The Coronation Academy is about the usual standard. With a few exceptions the paintings, for instance, are of a kind that will reassure teachers of art that their students learned the fundamental rules of composition, acquired a tolerable sense of colour and still know how to handle paint. The acres of ordinary and, at times, deplorable painting, and the cubic yards of uninspired sculpture will soon be forgotten, but the worth-while inches will be remembered.

Most of the few exciting works are in the imposing Gallery III and, indeed, the key to the whole show is in the huge *Teaching Staff of the Painting School of the Royal College of Art*, by Rodrigo Moynihan. Among those featured are Ruskin Spear on the couch, and John Minton, an isolated and doleful figure. The former is a fairly recent A.R.A. and the latter, surely, one of the next. But for these two, the Academy would be a poor show, indeed.

Though the influence of Sickert is obvious in Spear's work, there is, nevertheless, a highly important personal element in it. *The Pool Winners* is a fine snap-shot, painted with swift, witty ecstasy; while the two West London studies, *Near the Lyric Theatre* and *On Hammersmith Bridge* both have Spear's rare qualities of profundity, hung with jewellery.

The most interesting of the royal paintings (though one of the figures is not too readily identifiable) is *The Garter Investiture* by Simon Elwes, whose fresh, gay treatment, at least reproduces something of the decorative qualities of an impressive occasion. Two single portraits are worthy of special note: the head and shoulders of *Ernest Bevin* by the late Thomas Dugdale, whose muted crimson background, and calmly painted head are a fair interpretation of the statesman's qualities; and the full-length study of *Nevile Wallis*, the well-known art critic, by John Minton. This portrait, by one regarded by the previous president as an arch-rebel, is an excellent example of what a portrait should be. The sitter is entirely preoccupied with his job. Before he has even got rid of his hat, he is arrested by the qualities of a painting on an easel. The background of prints, etc. enhances the setting. It is curious that artists, in their own self portraits usually depict themselves at work—brush in hand before a canvas—yet so often they pose their sitters as respectable, anonymous ratepayers.

Here and there, lads of twenty or less attract attention, though running the age-old danger of sensationalism. *Christ Carrying the Cross* in a modern setting, by Robert J. Steele, and featuring a limousine and a crate of milk bottles, is a work of real virtuosity but is too deliberately intended to shock; though *The Gossips* in tempera by Michael Nokes is more single-minded. In this medium *The Crown of Roses and the Crown of Thorns*, by Merton (an adult) is about the last word in prettiness and bad taste.

In the outlying galleries water-colour, the glory of English art, has faded almost beyond recognition, Pitchforth being a notable exception; and the etchings, engravings, etc., are mostly pedestrian.

The position is much the same in sculpture. Anyone satisfied with technical excellence, that will not tempt a second glance, can have it by the cart-load. Now and again, fortunately, are glimpses that make us less forlorn. Epstein's fine head of *Mrs. McEvoy* is already well known; Will Soukop transforms a fishwife into a gauche, but wonder-stricken saint and Charoux's *Three-Quarter Stoneware Figure* of a peasant seems to be merging into Apollo, and one, at least, of the terra cotta heads by Arnold Machin has the *frissonnement* of surprise, sometimes found in the gothic figures on French cathedrals.

For anyone whose sole visit to an art exhibition is an annual visit to the Royal Academy, a pleasant enough afternoon is guaranteed; but the visitor for whom art is the wine of life will have few exhilarating moments.

G. S. SANDILANDS

EXHIBITION OF PHOTOGRAPHY

The Royal Photographic Society is holding a series of exhibitions in connection with its centenary celebrations at its house at 16, Princes Gate, London, S.W.7. The present exhibition, which will remain open until May 30th, is entitled "New Outlook in Photography" and illustrates the work of sixty-five leading British and foreign photographers. The photographs are marked by a dislike of formalism either in technique or composition, and attempt rather to capture momentary impressions than to be composed studies.

The exhibition is open on weekdays from 9.30 a.m. to 5.30 p.m. (Saturdays, 5 p.m.).

THE TAW AND TORRIDGE FESTIVAL

A festival of the arts will be celebrated from July 11th to 19th in the ancient boroughs of Bideford and Barnstaple. Apart from local manifestations of the arts (the Bideford silver band will be giving two concerts on the quay, and the first performance of *Don Juan*, a verse-drama by the chairman of the festival, Mr. Ronald Duncan, will be given in the Palace Theatre, Bideford), Mr. Benjamin Britten and Mr. Humphrey Lyttelton will be there to take part in the musical side of the festival. In addition, an exhibition of sculpture and of West Country landscape will be held in the Burton Gallery, Bideford.

The celebrations will be enlivened by a ball and two firework displays.

NOTES ON BOOKS

THE WORK OF THE MODERN POTTER IN ENGLAND. *By George Wingfield Digby. Murray*, 1952. 16*s*

Mr. Wingfield Digby's book, *The Work of the Modern Potter in England*, sets out, in the author's words, not only to illustrate by means of sixty-four plates the finest of the work of our artist potters since the early 1920's, but also to help us to under-

stand their point of view, and to show us by what standards their work may be appreciated.

Within the limits of such a small book, this is an extremely difficult, if not impossible task to undertake, and the author surmounts this obstacle by dealing mainly with stoneware (with which he maintains all English potters are primarily concerned) and ignores completely many sections of the great field of ceramics which have been growing up in England since the end of the war. One feels that he has missed a good opportunity by setting himself these narrow limits, for if he had left out or reduced the section on biographical notes, and used this space to consider, even though briefly, some aspects of modern ceramic sculpture and majolica ware, the value of the book would have been doubled.

The interesting question of the extent of oriental influence on English pottery, in a discussion of which the author asks his readers, "Is it right to charge them (the English potters) with plagiarism?" is one which is certainly well worthy of consideration. Certainly the excellent photographs show that in stoneware we have no characteristically national style other than a discriminate enthusiasm for the Far East, which must be checked if English studio pottery in the future is to have the reputation it deserves.

The work of Bernard Leach, who spent twelve years of his life working and studying in the Far East is discussed at length, and we are able to see how he has produced, as a result of his complete comprehension of Chinese forms and techniques, beautiful and valuable work. For his followers, however, with a few exceptions the Chinese style has been a difficult distant mis-read thing. The three main problems—glazing, form and decoration—have not been equally realized. Chinese glazes have been copied by the experimenters down to the last crackle. The simplicity of the early Chinese pot forms have had a good effect on all pottery. Much of the decoration that we are shown throughout the book, with the exception of Leach, Shoji Hamada and Cardew, seems lifeless, in some cases producing nothing but a vulgarization of the Chinese ideas; and this would have seemed a very good reason for the author to have extended his critical survey to cover the more imaginative and colourful work of some of the post-war artist potters.

There is an excellent chapter on how pottery is made, brilliantly and convincingly written, which will be intelligible both to the potter and the layman, and of value to all who read it.

If the author had presented this book as a survey of the development of English pottery between the wars, it would have been excellent, but as a book on the work of the modern potter it is disappointing; for there is little in it that is post-war in spirit, or of our day.

WILLIAM NEWLAND

NEW KINGDOM ART IN ANCIENT EGYPT. *By Cyril Aldred. Alec Tiranti,* 1951. 15s

This is the third in an excellent series of small handbooks on Egyptian art by the present author in which he traces its development from its beginnings. The art of ancient Egypt by its self-possessed and calm dignity has a great appeal to a distracted modern world. It is well known from many illustrated publications, but there is room for a fresh approach by a scholar, interested as is the author, in the problems of ancient techniques and craftsmanship. The art of Egypt first reached its full flower in the Old Kingdom, during the third millenium B.C. Already then in the service of the Pharaoh and the state religion all the principal branches of art were explored, the various forms and types were established and received their most vigorous expression. The Middle Kingdom, representing the XI and XII Dynasties, maintained these traditions at a high level, but after the long foreign domination of the Hyksos Kings, something of that vigour disappeared. The culture of the

New Kingdom, as it is called, and more specifically the XVIII Dynasty, though a brilliant revival, is in fact the elegant but artificial art of a Silver Age, luxurious, sophisticated, but almost uninspired. Its smooth façade was broken for a brief space in the fourteenth century B.C. by the dynamic religious and artistic innovations of the gifted Pharaoh Akhenaten, but in the furiously reactionary revolt which caused (or followed) his demise, all his works were systematically effaced, as far as they could be, until rediscovered by the prying eyes of modern excavators. Artistic freedom and naturalism were repressed in favour of the old-established conventions, and Egyptian art settled down to a process of inevitable fossilization and decay. Of that revolutionary phase, the so-called Amarna period, Mr. Aldred gives an interesting and detailed account. With the end of the XVIIIth Dynasty, a few years late, his book rather abruptly closes, though the New Kingdom and its art continued for another two and a half centuries.

The main part of the text is an essay describing the features of New Kingdom art with sensitive and well-informed appreciation. The fifty-six plates containing one hundred and seventy-four illustrations in half tone, make up a valuable handbook for students, though not all the reproductions are of equal merit. Most branches of art are represented, including goldsmith's work and glass. Some, such as a charming ivory grasshopper, are too little known. The illustrations are duly catalogued. But alas! the printing type is rather ugly and cheap looking—one of the penalties of inflated printing costs which many books have to pay to-day. Yet the useful map of Egypt, with the place-names in imitation typescript, could surely have been better lettered. For after all, the book is not so cheap.

R. D. BARNETT

MODERN ENGLISH PAINTERS—SICKERT TO SMITH. *By Sir John Rothenstein. Eyre & Spottiswoode*, 1952. 25*s*

For those who wish for information on those painters—seventeen in all, including Augustus John, Wilson Steer, McEvoy, Orpen and their contemporaries, there could be no better book of reference.

It is attractively written, admirable in its analysis and authoritative in its insight and research. Sir John, in fact, has delved so deeply into their characteristics and personalities, that one cannot help feeling that there is a motive behind this, for he first of all carefully builds up his subject and then proceeds to pull him to pieces. This treatment he applies to almost everybody in the book, so consistently that it is hard to avoid wondering why. This first volume is a preliminary canter before the appearance of a second volume, and since coming events cast their shadows before them, the discerning reader will assume that its purpose is not too hard to seek. The list of names of those with whom the second volume will deal are mostly of the ultra-modern group, and since the Tate Gallery is becoming the Mecca of experimental doodling, it is safe to assume that they will receive a generous measure of praise at the expense of the old actors who have now been so cleverly pushed off the stage.

Mr. Stephen Bone in the *Daily Telegraph* struck the right note when, amongst other things, he pointed out the absence of John Sargent. No doubt Sir John must have realized that it would be by no means easy convincingly to pooh pooh Sargent as he has the lesser lights. His apology for the omission of this great painter would no doubt be on the grounds that Sargent was an American.

Such an argument, however, would not hold water, for he includes that very minor artist Lucien Pisarro, who was of French origin.

When recently visiting the National Gallery (the Trafalgar Square branch) in the company of a painter of distinction, we both came to the conclusion that Sargent would not be so very far behind on Judgment Day with the best of the recognized old masters.

BERNARD ADAMS

SHORT NOTES ON OTHER BOOKS

ENGINEERING DRAWING. *By H. T. Davey and R. J. Wilkins. Macdonald,* 1952. 45*s*

The authors have here set out the fundamental principles of engineering drawing, with exercises, for students who are assumed to have little or no previous knowledge of the subject.

GEOMETRY AND THE IMAGINATION. *By D. Hilbert and S. Cohn-Vossen. New York, Chelsea publishing company,* 1952

This is the translation of a book first published in Germany in 1932; it seeks to indicate the approach to geometry through visual intuition, to bring about a greater enjoyment of mathematics by offering the reader figures that may be looked at, instead of formulæ.

FABRIC PRINTING. *By Allan Smith. Warne,* 1953. 6*s*

The author describes the materials and methods of potato, stick, and lino-block printing, and gives advice on suitable designs. The book is illustrated with diagrams and with examples of work done by the author and his pupils.

MAKING COLOUR PRINTS: AN APPROACH TO LINO CUTTING. *By John Newick. Leicester, Dryad Press,* 1952. 12*s* 6*d*

The author maintains that the lino-cut is capable of much more in style and expressiveness than the usual black and white print displays; the examples illustrated, the work of his pupils, confirm that large and ambitious work in colour is possible. His instructions cover all stages and materials involved in making a print, and are illustrated with drawings as well as prints.

MODERN APPLIED PHOTOGRAPHY. *By G. A. Jones. Temple Press,* 1953. (*Technical trends series.*) 9*s* 6*d*

The uses of photography as a tool in science and industry are here described and illustrated. They include recording, high-speed photography, infra-red and ultra-violet photography, and radiography. There is a short bibliography.

FROM THE JOURNAL OF 1853

VOLUME I. 13*th May,* 1853

From the report of a lecture delivered by Dr. Hunter on the Exhibition at Madras of Arts, Manufactures and Raw Produce.

. . . . One of the curious and unlooked-for results of the great Exhibition of 1851 was, satisfying the public that very little is known, even in India, of what the country can and does produce; and many an old Indian was surprised to find how little he knew of the products, the resources, and the industry of the natives. Another startling result which experience is proving to be correct is, that many of the Indian patterns for manufactures are designed and arranged upon better and simpler principles than those which regulate the artistic designs of Europe. I had often suspected this to be the case, and I hope to have the opportunity during the month of March of showing from some simple native designs which have been executed by the pupils in our school, that the natives excel most European artists in the tasteful arrangement of colours; and that a flowing, graceful, and clear style of outline, forms the basis of their instructions in drawing, painting, and the arrangement of architectural ornament.